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Modification of the Ranking of Alternatives with Weights of Criterion (RAWEC) Method and Improvement with Fermatean Fuzzy numbers

Duško Tešić[1,*], Darko Božanić[1,*], Sankar Prasad Mondal[2], Adis Puška[3]

[1] Military Academy, University of Defence, Belgrade, Serbia
[2] Department of Applied Mathematics, Maulana Abul Kalam Azad University of Technology, West Bengal, India
[3] Government of Brčko District of Bosnia and Herzegovina, Brčko, Bosnia and Herzegovina

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ABSTRACT

This paper presents a modified version of the Ranking of Alternatives with Weights of Criterion (RAWEC) method, improved by the application of Fermatean fuzzy (FF) numbers, with the aim of solving decision-making problems under conditions of uncertainty. As a contribution to the field of multi-criteria decision making (MCDM), the FF-RAWEC method offers a solid mathematical foundation and shows flexibility through different decision scenarios—when the criteria are of benefit, cost, or mixed type. Numerical examples illustrate the practical application of the method, while sensitivity analysis confirms its stability. In addition, the comparative analysis shows a high correlation of ranks with other methods, which further confirms the validity and reliability of the proposed method. FF-RAWEC successfully integrates the advantages of FF logic, making it suitable for solving real-world problems involving imprecise or subjective information. Its adaptability and consistency indicate great potential for further application and development in engineering and social decision-making contexts.

1. Introduction

Multi-criteria decision-making (MCDM) is an approach used to select the best alternative in situations where decisions are made based on multiple, often conflicting, criteria. These methods are applied in a number of fields such as banking sector [1], military [2, 3], defense industry [4], engineering [5], performance management [6], automotive industry [7, 8], economics [9], logistics [10], etc. All MCDM methods share the common goal of structuring complex problems and enabling rational comparisons of alternatives, but they differ in their approach: some rely on valuation, others on comparison, utility, preference modeling, or optimization [11]. One of the younger methods for determining the optimal alternative is the Ranking of Alternatives with Weights of Criterion (RAWEC) method. This method was introduced in 2024 [12] and so far it has found its application in numerous research. In the first publication of this paper [12], the authors investigated the optimal location

* Corresponding author.
E-mail address: dbozanic@yahoo.com

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selection for agricultural distribution centers, which significantly affects the growth of the agricultural industry and regional development. Using this method, the authors analyzed the Brčko District in Bosnia and Herzegovina as a potential location. The results showed that the RAWEC method is simple and reliable for ranking alternatives, with consistent and stable results. Subsequently, Trung et al. [13] published a paper in which the research focuses on addressing the limitations of the RAWEC method, especially when there is at least one zero element in the decision matrix and proposes an alternative normalization method that is suitable for such situations. Dündar [14] focuses his research on the prioritization of rural development programs coordinated by the Agriculture and Rural Development Support Agency in Turkey, using the Defining Interrelationships Between Ranked Criteria (DIBR) method to determine the weight of criteria. The RAWEC method was used to rank the effectiveness of seventeen rural development programs implemented during the Instrument for Pre-Accession Assistance Rural Development-II period. In addition to the use of the crisp method, it is also enhanced by various theories that treat uncertainty well. The improvement of the method with Fuzzy theory has been demonstrated in various fields. Nedeljković et al. [15] in this paper, analyze the choice of cabbage sales channels using the fuzzy set approach with the Method based on the Removal Effects of Criteria (MEREC) and RAWEC methods. The fuzzy set approach enables the evaluation of qualitative criteria based on the linguistic values of experts, while the RAWEC method shows that online sales give the best results. The integration of MEREC and RAWEC methods enabled the precise ranking of different sales channels, confirming the effectiveness of these methods in MCDM. The authors in this paper [16] investigate the effectiveness of fuzzy multi-criteria decision-making methods, especially Fuzzy Weight by Envelope and Slope (F-WENSLO) and F-RAWEC, for the evaluation of potential locations for wind farms. An evaluation of five sites in the province of Sivas in Turkey showed that Ulaş and Kangal are the most suitable for the installation of wind farms due to favorable wind conditions, altitude and social acceptance. The study emphasizes the importance of integrating multiple criteria and expert judgments in the decision-making process, confirming that fuzzy methods can effectively support the selection of sites for wind farms. Puška et al. [17] investigate the selection of electric tractors using MCDM methods, especially the Fuzzy-Rough (FR) methodology. Using the FR Simple Weight Calculation (SIWEC) method, maintenance was found to be the most important criterion, while the FR RAWEC method showed that the Solectrac e25 is the most suitable tractor for small farms in the Semberija region, Bosnia and Herzegovina. The study emphasizes the importance of using electric tractors to reduce environmental pollution and the development of an improved FR methodology for the harmonization of expert assessments. The application of the neutrosophic approach to the RAWEC method is presented in [18]. In this paper, the authors investigate the selection of materials for the construction of drone wings. The Single Value Triangular Neutrosophic Sets (SVTNSs)-Logarithm Methodology of Additive Weights (LMAW) method for calculating criteria weights and the SVTNSs-RAWEC method for ranking alternatives are presented, which eliminate the need for pairwise comparisons and save time. Research has shown that these methods effectively support material selection in conditions of uncertainty, confirming their stability and reliability through sensitivity analysis. Since the RAWEC method has not yet been improved using Fermatean Fuzzy numbers, an additional gap arises for this research.

The paper presents a modified RAWEC method that has been improved using Fermatean fuzzy numbers, for which a mathematical basis is given, with the necessary computational operations. After describing the FF-RAWEC method, numerical examples are given and the method is tested with intuitive initial decision matrices, in situations when: 1) all criteria are of the Benefit type; 2) all criteria are of the Cost type; and 3) the criteria are of both the Benefit and Cost types. For the purpose of validation, an analysis of the sensitivity of the output results to changes in the weights of the

criteria was performed, as well as a Comparative Analysis, i.e. a comparison of the results of the FF-RAWEC method with the results of other methods from other research.

2. Fermatean Fuzzy RAWEC (FF-RAWEC) method

In order to successfully modify the RAWEC method and implement Fermatean fuzzy numbers in the method, it was necessary to conduct several phases of research, shown in Figure 1.

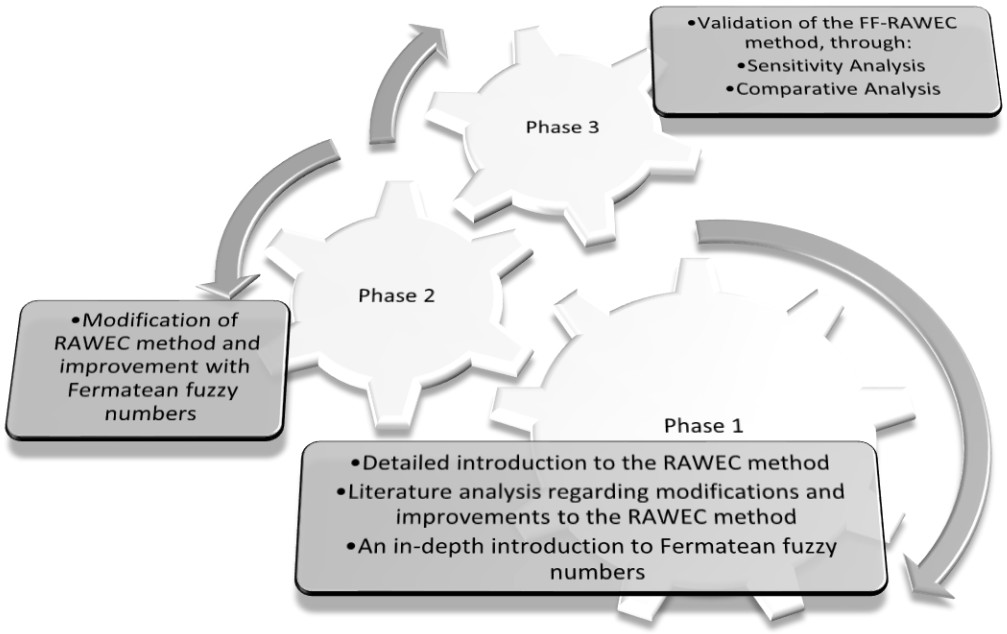

Fig. 1. Research algorithm

In order to improve this method using Fermatean Fuzzy numbers, it is necessary to know their basics and computational operations with these numbers. According to Senapati and Yager [19], the Fermatean fuzzy number ($FFA(z)=(\alpha_A(z),\beta_A(z))$) can be represented as, where $\alpha_A(z)$ represents the degree of belonging and $\beta_A(z)$ the degree of non-belonging of element *z* to set *A* and where $\alpha_A(z)$ and $\beta_A(z)$ have values from *0* to *1*, with the condition that $0\leq\alpha_A(z)^3+\beta_A(z)^3\leq 1$. The number can be represented more simply as $FFA=(\alpha_A,\beta_A)$. The score function of the Fermatean fuzzy number is calculated using Eq. (1), the accuracy function is calculated using Eq. (2) and the indeterminacy degree using Eq. (3):

$$score(A)=\alpha_A{}^3-\beta_A{}^3 \quad (1)$$

$$acc(A)=\alpha_A{}^3+\beta_A{}^3 \quad (2)$$

$$\Pi_A=\sqrt[3]{1-\alpha_A{}^3-\beta_A{}^3} \quad (3)$$

Let $FFA=(\alpha_A,\beta_A)$ and $FFB=(\alpha_B,\beta_B)$ be two Fermatean fuzzy numbers. In order to rank the Fermatean fuzzy numbers, the following rules must be observed [19]:

$$\begin{gathered} score(FF\,A) < score(FF\,B) \Rightarrow A < B \\ score(FF\,A) > score(FF\,B) \Rightarrow A > B \\ score(FF\,A) = score(FF\,B) \Rightarrow acc(FF\,A) < acc(FF\,B) \Rightarrow A < B \\ acc(FF\,A) > acc(FF\,B) \Rightarrow A > B \\ acc(FF\,A) = acc(FF\,B) \Rightarrow A = B \end{gathered} \quad (4)$$

Basic calculation operations, necessary for the application of Fermatean fuzzy numbers, are given in the following text, according to [19, 20], Eqs. (5)-(10):

$$FF\,A + FF\,B = \left(\sqrt[3]{\alpha_A^{\,3} + \alpha_B^{\,3} - \alpha_A^{\,3}\alpha_B^{\,3}}, \beta_A\beta_B \right) \quad (6)$$

$$FF\,A - FF\,B = \left(\sqrt[3]{\frac{\alpha_A^{\,3} - \alpha_B^{\,3}}{1 - \alpha_B^{\,3}}}, \frac{\beta_A}{\beta_B} \right) \Leftrightarrow \alpha_A \geq \alpha_B, \beta_A \leq \min\left\{ \beta_B, \frac{\beta_B \Pi_A}{\Pi_B} \right\} \quad (6)$$

$$FF\,A\,x\,FF\,B = \left(\alpha_A\alpha_B, \sqrt[3]{\beta_A^{\,3} + \beta_B^{\,3} - \beta_A^{\,3}\beta_B^{\,3}} \right) \quad (7)$$

$$FF\,A \,/\, FF\,B = \left(\frac{\alpha_A}{\alpha_B}, \sqrt[3]{\frac{\beta_A^{\,3} - \beta_B^{\,3}}{1 - \beta_B^{\,3}}}, \right) \Leftrightarrow \alpha_A \leq \min\left\{ \alpha_B, \frac{\alpha_B \Pi_A}{\Pi_B} \right\}, \beta_A \geq \beta_B \quad (8)$$

$$\mu\,x\,FF\,A = \left(\sqrt[3]{1 - \left(1 - \alpha_A\right)^{\mu}}, \beta_A^{\,\mu} \right) \quad (9)$$

$$FF\,A^{\mu} = \left(\alpha_A^{\,\mu}, \sqrt[3]{1 - \left(1 - \beta_A\right)^{\mu}} \right) \quad (10)$$

Respecting the RAWEC method algorithm [12] and the previously mentioned properties and calculation operations of Fermatean fuzzy numbers, and in accordance with [19, 20], the Fermatean fuzzy RAWEC method (FF-RAWEC) was developed, with the following steps:

Step 1 – Formation of the initial decision matrix $IDM = \left[FF\,x_{ij} \right]_{mxn}$, where $FF\,x_{ij}$ represents the Fermatean fuzzy element of the initial decision matrix, i.e. the evaluation value of each alternative $A_i \Rightarrow i = (1,2,\ldots m)$, according to each criterion $C_j \Rightarrow j = (1,2,\ldots n)$. In the case that several experts $E_e \Rightarrow e = (1,2,\ldots p)$ evaluated alternatives, in order to aggregate and obtain a unique initial decision matrix, one of the Fermatean fuzzy operators can be used, and we recommend the use of the Fermatean fuzzy weighted power geometric (FFWPG) operator, Eq. (11):

$$FFWPG = \left(\sqrt[3]{\left(1 - \prod_{e=1}^{p} (1 - \alpha_{X_e}^{\,3})^{w_e} \right)}, \sqrt[3]{\left(1 - \prod_{e=1}^{p} (1 - \beta_{X_e}^{\,3})^{w_e} \right)} \right) \quad (11)$$

Step 2 – Formation of fermatean fuzzy normalized initial decision matrix $NIDM = \left[FF\,\eta_{ij} \right]_{mxn}$, where double normalization is performed as follows:

$$FF\,\eta_{ij} = FF\,x_{ij} = \left(\alpha_{X_{ij}}, \beta_{X_{ij}} \right), FF\,\eta'_{ij} = FF\,x^{c}_{ij} = \left(\beta_{X_{ij}}, \alpha_{X_{ij}} \right), for\ Benefit\ criteria \quad (12)$$

$$FF\,\eta_{ij} = FF\,x^{c}_{ij} = \left(\beta_{X_{ij}}, \alpha_{X_{ij}} \right), FF\,\eta'_{ij} = FF\,x_{ij} = \left(\alpha_{X_{ij}}, \beta_{X_{ij}} \right), for\ \text{Cost}\ criteria \quad (13)$$

Step 3 – Calculation of Fermatean fuzzy matrix deviation $\Delta = \left[FF\,\delta_{ij} \right]_{mxn}$, in relation to the weight coefficients of the criteria (w_j), Eqs. (14)-(15):

$$FF\,\delta_{ij} = \sum_{i=1}^{n} w_j \cdot \left(1 - FF\,\eta_{ij}\right) \tag{14}$$

$$FF\,\delta^{'}_{ij} = \sum_{i=1}^{n} w_j \cdot \left(1 - FF\,\eta^{'}_{ij}\right) \tag{15}$$

Step 4 – Calculation of the values of the method (Ω_i), using Eqs. (1) and (16):

$$\Omega_i = \delta^{'}_{ij} - \delta_{ij} \tag{16}$$

After obtaining the value of the method, the ranking of alternatives is performed, in such a way that the higher value has priority in the final ranking.

3. Method testing

In order to test the method, three scenarios were formed, which have in common that five criteria $C_j = \left(C1, C2, \ldots C5\right)$ and four alternatives $A_i = \left(A1, A2, \ldots A4\right)$ were identified, and all criteria have equal value $w_j = \left(w1, w2, \ldots w5\right) = 0.2$, with the following properties:

Scenario 1 - All criteria are of Benefit type, and the values of alternatives according to each criterion are ordered from the largest (A1) to the smallest (A4), i.e. the fermatean fuzzy initial decison matrix IDM-1 is presented in Table 1:

Table 1
Fermatean fuzzy initial decision matrix IDM-1

Alternative/Criteria	C1	C2	C3	C4	C5
Criteria type	Benefit	Benefit	Benefit	Benefit	Benefit
A1	(0.9,0.1)	(0.9,0.1)	(0.9,0.1)	(0.9,0.1)	(0.9,0.1)
A2	(0.7,0.3)	(0.7,0.3)	(0.7,0.3)	(0.7,0.3)	(0.7,0.3)
A3	(0.3,0.7)	(0.3,0.7)	(0.3,0.7)	(0.3,0.7)	(0.3,0.7)
A4	(0.1,0.9)	(0.1,0.9)	(0.1,0.9)	(0.1,0.9)	(0.1,0.9)

Scenario 2 - All criteria are of Cost type, and the values of alternatives according to each criterion are ordered from the smallest (A1) to the largest (A4), i.e. the IDM-2 is presented in Table 2:

Table 2
Fermatean fuzzy initial decision matrix IDM-2

Alternative/Criteria	C1	C2	C3	C4	C5
Criteria type	Cost	Cost	Cost	Cost	Cost
A1	(0.1,0.9)	(0.1,0.9)	(0.1,0.9)	(0.1,0.9)	(0.1,0.9)
A2	(0.3,0.7)	(0.3,0.7)	(0.3,0.7)	(0.3,0.7)	(0.3,0.7)
A3	(0.7,0.3)	(0.7,0.3)	(0.7,0.3)	(0.7,0.3)	(0.7,0.3)
A4	(0.9,0.1)	(0.9,0.1)	(0.9,0.1)	(0.9,0.1)	(0.9,0.1)

Scenario 3 – Criteria C1 and C3 are Cost type, while the others are Benefit, and the values of alternatives according to each criterion are ordered in such a way that with the Benefit criteria, the alternatives are rated from the largest (A1) to the smallest (A4), while with the Cost criteria, the alternatives are rated from the smallest (A1) to the largest (A4), i.e. the IDM-3 is presented in Table 3:

Table 3
Fermatean fuzzy initial decision matrix IDM-3

Alternative/Criteria	C1	C2	C3	C4	C5
Criteria type	Cost	Benefit	Cost	Benefit	Benefit
A1	(0.1,0.9)	(0.1,0.9)	(0.1,0.9)	(0.1,0.9)	(0.1,0.9)
A2	(0.3,0.7)	(0.3,0.7)	(0.3,0.7)	(0.3,0.7)	(0.3,0.7)
A3	(0.7,0.3)	(0.7,0.3)	(0.7,0.3)	(0.7,0.3)	(0.7,0.3)
A4	(0.9,0.1)	(0.9,0.1)	(0.9,0.1)	(0.9,0.1)	(0.9,0.1)

In the following text, the mentioned scenarios will be implemented in the proposed FF-RAWEC method and the application steps will be shown.

3.1. Scenario 1

Given that Fermatean fuzzy IDM-1 (all criteria are of Benefit type) is presented in Table 1, we move on to the second step of applying the method.

Step 2 – Applying Eq. (12), double normalization of elements of Fermatean fuzzy IDM is performed (Table 4):

Table 4
Fermatean fuzzy normalized initial decision matrix IDM-1

Ai/Cj	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5
			$FF\eta_{ij}$					$FF\eta'_{ij}$		
A1	(0.9,0.1)	(0.9,0.1)	(0.9,0.1)	(0.9,0.1)	(0.9,0.1)	(0.1,0.9)	(0.1,0.9)	(0.1,0.9)	(0.1,0.9)	(0.1,0.9)
A2	(0.7,0.3)	(0.7,0.3)	(0.7,0.3)	(0.7,0.3)	(0.7,0.3)	(0.3,0.7)	(0.3,0.7)	(0.3,0.7)	(0.3,0.7)	(0.3,0.7)
A3	(0.3,0.7)	(0.3,0.7)	(0.3,0.7)	(0.3,0.7)	(0.3,0.7)	(0.7,0.3)	(0.7,0.3)	(0.7,0.3)	(0.7,0.3)	(0.7,0.3)
A4	(0.1,0.9)	(0.1,0.9)	(0.1,0.9)	(0.1,0.9)	(0.1,0.9)	(0.9,0.1)	(0.9,0.1)	(0.9,0.1)	(0.9,0.1)	(0.9,0.1)

Step 3 – After obtaining the normalized values of IDM-1, using Eqs. (14)-(15), the elements of the Fermatean fuzzy deviation matrix are calculated (Table 5):

Table 5
Fermatean fuzzy deviation matrix

Ai/Cj	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5
			$FF\delta_{ij}$					$FF\delta'_{ij}$		
A1	(0.39,1)	(0.39,1)	(0.39,1)	(0.39,1)	(0.39,1)	(0.91,0.92)	(0.91,0.92)	(0.91,0.92)	(0.91,0.92)	(0.91,0.92)
A2	(0.58,1)	(0.58,1)	(0.58,1)	(0.58,1)	(0.58,1)	(0.8,0.97)	(0.8,0.97)	(0.8,0.97)	(0.8,0.97)	(0.8,0.97)
A3	(0.8,0.97)	(0.8,0.97)	(0.8,0.97)	(0.8,0.97)	(0.8,0.97)	(0.58,1)	(0.58,1)	(0.58,1)	(0.58,1)	(0.58,1)
A4	(0.91,0.92)	(0.91,0.92)	(0.91,0.92)	(0.91,0.92)	(0.91,0.92)	(0.39,1)	(0.39,1)	(0.39,1)	(0.39,1)	(0.39,1)

Step 4 – Then, the values of the method are calculated, using Eqs. (2) and (16), and the values and ranking of the alternatives are presented in Table 6:

Table 6
The values of the method and ranking of the alternatives for IDM-1

	Ω_i	Rank
A1	1.456	1
A2	0.632	2
A3	-0.632	3
A4	-1.456	4

The ranking of the alternatives that was obtained is expected, considering the way in which the IDM was formed, which indicates the correctness of the method.

3.2. Scenario 2 and 3

By implementing the Fermatean fuzzy IDM-2 (all criteria are of Cost type – Table 2) and IDM-3 (some criteria are Benefit and some of them are Cost type – Table 3), in the FF-RAWEC method, according to the same principle as in Scenario 1, the following values of the method and the ranking of the alternatives are obtained (Table 7):

Table 7
The values of the method and ranking of the alternatives for IDM-2

	Ω_i	Rank	Ω_i	Rank
	IDM-2		IDM-3	
A1	1.456	1	1.456	1
A2	0.190	2	0.541	2
A3	-0.091	3	-0.442	3
A4	-0.232	4	-0.841	4

As with Scenario 1, in these two scenarios, the correctness of the method was proven. In order to check the validity of the method, a comparative analysis was carried out, and the results obtained are shown in the rest of the text.

4. Comparative Analysis

In order to compare the obtained results with the results of other methods, when the same data are used as input, i.e. the same initial decision matrix with the same weight coefficients of the criteria, a comparative analysis [21] was performed in relation to six other Fermatean Fuzzy methodologies and methods: Fermatean Fuzzy Weighted Average (FFWA), Fermatean Fuzzy Weighted Geometric (FFWG), Fermatean Fuzzy Weighted Power Average (FFWPA) and Fermatean Fuzzy Weighted Power Geometric (FFWPG), Fermatean Fuzzy Weighted Product Method (FF-WPM), and Fermatean Fuzzy Combinative Distance-based Assessment (FF-CODAS). Four Fermatean fuzzy methodologies are presented in [19], where the authors deal with the improvement of the decision-making process in conditions of uncertainty through the application of Fermatean fuzzy sets, introducing four new aggregation operators: FFWA, FFWG, FFWPA and FFWPG. These operators enable a more flexible and precise aggregation of information in multi-criteria decision making (MCDM), and the authors analyze in detail their mathematical properties and correctness conditions. The effectiveness of the proposed approach is demonstrated through a case study of choosing a site for building a house, thus confirming its practical applicability. The introduction of three new mathematical operations - subtraction, division and arithmetic mean - over Fermatean fuzzy numbers, which expands the theoretical framework for working with uncertain information, is presented in [20]. Based on these operations, the FF-WPM method was developed, which is used to solve the multi-criteria decision-making problem. The effectiveness of the proposed model is demonstrated through the example of choosing the most suitable method for bridge construction, thus confirming its practical applicability in engineering decision-making. The authors in [22] focus on solving the smartphone brand selection problem, and in this context, apply the FF-CODAS method to more accurately express subjective ratings and rank alternatives based on their distance from the negative ideal. The results show that FF-CODAS provides stable, robust and consistent decision making, which is confirmed by sensitivity analysis and comparison with other MCDM methods.

The application of the proposed FF-RAWEC method to decision-making problems and examples in the previously mentioned researches, in comparison with the original methods and methodologies, are presented in Table 8.

Table 8
Comparative analysis

FF-RAWEC	FF-CODAS [22]	FF-RAWEC	FFWA [19]	FFWG [19]	FFWPA [19]	FFWPG [19]	FF-WPM [20]
9	3	1	2	2	2	2	1
3	4	4	4	4	4	4	3
2	2	2	1	1	1	1	2
1	1	3	3	3	3	3	4
5	11						
6	6						
9	7						
8	10						
12	9						
7	8						
13	13						
14	14						
11	12						
4	5						

Applying the Pearson's correlation coefficient [23], the following correlation values of the FF-RAWEC method are obtained in relation to the ranks obtained in the above studies (Figure 2):

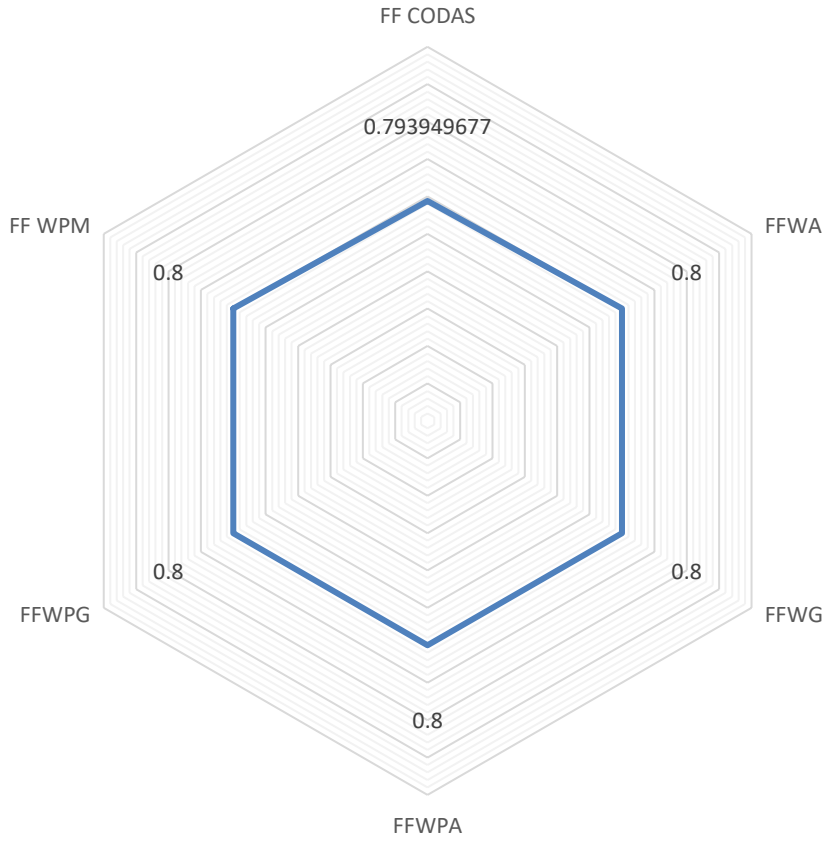

Fig. 2. Pearson's correlation coefficient values

Given that this is a strong correlation of ranks [24], it can be concluded that the method is valid.

5. Sensitivity Analysis

Different approaches of sensitivity analysis have been presented in different studies [25-27]. Sensitivity analysis was conducted on the changes in criterion weights in the smartphone brand selection problem [22]. The initial decision matrix in this research is presented in Table 9.

Table 9
Fermatean fuzzy initial matrix [22]

Ai/Cj	C1	C2	C3	C4	C5	C6	C7
A1	(0.68,0.23)	(0.73,0.19)	(0.75,0.17)	(0.73,0.19)	(0.74,0.17)	(0.75,0.17)	(0.77,0.17)
A2	(0.59,0.33)	(0.67,0.24)	(0.69,0.21)	(0.69,0.23)	(0.72,0.20)	(0.69,0.24)	(0.72,0.19)
A3	(0.71,0.21)	(0.78,0.16)	(0.78,0.15)	(0.76,0.17)	(0.79,0.14)	(0.8,0.14)	(0.79,0.14)
A4	(0.80,0.17)	(0.83,0.13)	(0.85,0.13)	(0.81,0.14)	(0.82,0.13)	(0.85,0.12)	(0.85,0.13)
A5	(0.61,0.30)	(0.69,0.23)	(0.66,0.24)	(0.65,0.25)	(0.71,0.21)	(0.69,0.22)	(0.69,0.22)
A6	(0.60,0.30)	(0.68,0.22)	(0.66,0.24)	(0.63,0.27)	(0.68,0.23)	(0.69,0.21)	(0.70,0.21)
A7	(0.47,0.42)	(0.56,0.34)	(0.54,0.36)	(0.55,0.35)	(0.54,0.37)	(0.57,0.33)	(0.55,0.34)
A8	(0.46,0.43)	(0.56,0.34)	(0.57,0.33)	(0.53,0.37)	(0.57,0.33)	(0.59,0.31)	(0.57,0.33)
A9	(0.49,0.40)	(0.55,0.35)	(0.52,0.37)	(0.51,0.38)	(0.53,0.37)	(0.51,0.38)	(0.50,0.39)
A10	(0.55,0.35)	(0.55,0.35)	(0.58,0.33)	(0.57,0.32)	(0.58,0.32)	(0.64,0.26)	(0.59,0.31)
A11	(0.49,0.39)	(0.55,0.36)	(0.51,0.40)	(0.47,0.42)	(0.50,0.40)	(0.53,0.36)	(0.53,0.36)
A12	(0.35,0.53)	(0.44,0.46)	(0.42,0.48)	(0.46,0.45)	(0.47,0.44)	(0.46,0.43)	(0.44,0.46)
A13	(0.47,0.42)	(0.53,0.38)	(0.51,0.40)	(0.44,0.45)	(0.53,0.37)	(0.60,0.29)	(0.55,0.35)
A14	(0.58,0.32)	(0.68,0.22)	(0.68,0.22)	(0.64,0.25)	(0.69,0.21)	(0.68,0.22)	(0.69,0.21)

For the purposes of this analysis, weight change scenarios were created (Figure 3), which were then applied in the FF-RAWEC method.

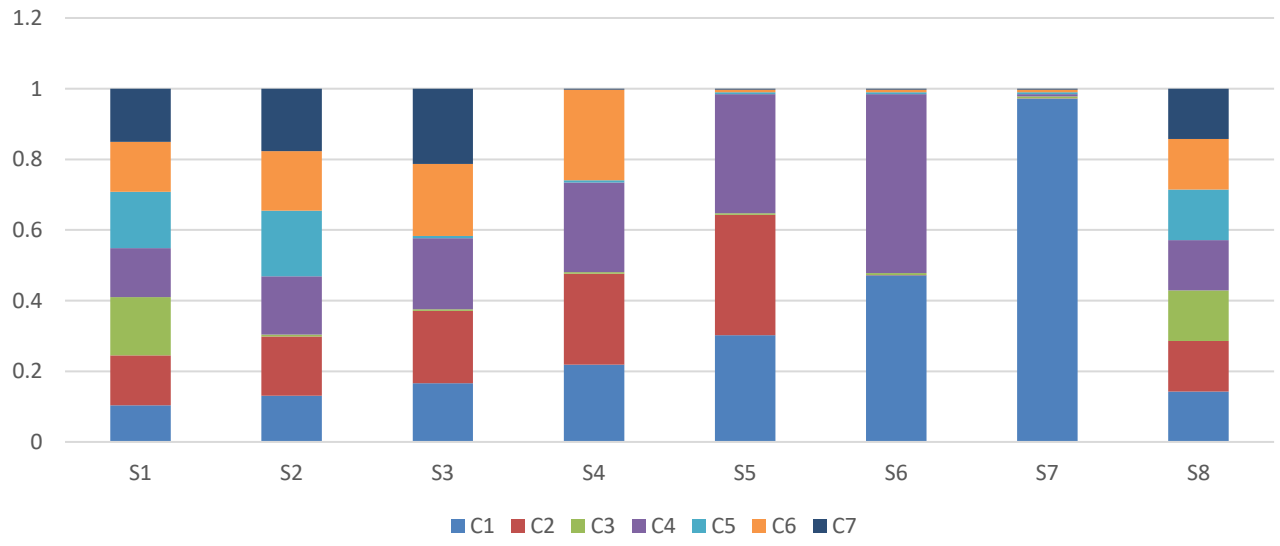

Fig. 3. Scenarios of changes in weight coefficients of criteria

The first scenario represents the existing ranking with defined criteria weights from the research (for comparison). In scenarios S2-S7, part of the value was subtracted from the most significant, and then from the next criterion in terms of importance, and allocated equally to the others. In scenario S8, all criteria have equal value. By applying the criteria weights change scenarios (Figure 3) in the FF-RAWEC method, the following alternative rankings are obtained (Table 10):

Table 10
Sensitivity analysis

	S1	S2	S3	S4	S5	S6	S7	S8
A1	9	9	9	9	7	5	3	9
A2	3	3	3	3	3	1	10	3
A3	2	2	2	2	2	2	13	2
A4	1	1	1	1	1	10	14	1
A5	5	5	5	5	5	8	12	5
A6	6	6	6	6	6	9	11	6
A7	9	9	9	9	7	5	3	9
A8	8	8	8	8	9	7	2	8
A9	12	12	13	12	11	12	6	12
A10	7	7	7	7	10	11	8	7
A11	13	13	12	13	12	13	7	13
A12	14	14	14	14	13	4	1	14
A13	11	11	11	11	14	14	5	11
A14	4	4	4	4	4	3	9	4

As can be concluded from Table 10, the method is sensitive exclusively to larger weight changes, as well as in cases where decisions are made based on one or two criteria, that is, when the values of all other criteria are reduced to an insignificant value. When analyzing the initial decision matrix (Table 9), for criterion C1, which is of the Cost type, from the research [22], in scenario S7, where a decision is made only on the basis of this criterion, so it is the simplest to perform the analysis, it is clear that this criterion has the lowest value according to alternative A12, and considering that it is a Cost criterion, it is imposed that this is the optimal alternative. Based on all the above, it can be concluded that the FF-RAWEC method gives consistent results and is not sensitive to minor changes in the weighting coefficients of the criteria.

5. Conclusions

MCDM methods are a key tool in the analysis of complex decision-making problems, namely in situations where it is necessary to simultaneously consider several different criteria on the basis of which alternatives are considered. Their application enables rational and transparent decision-making, which makes them indispensable in the decision-making process. The improvement of existing methods in various areas that well treat imprecision and incomplete data, enable these methods to make decisions under conditions of uncertainty.

In this paper, a modification and improvement of the RAWEC method using Fermatean fuzzy numbers was performed. Based on the presented results and the conducted analyses, it can be concluded that the modified FF-RAWEC method represents a significant contribution to the field of MCDM. The paper presents in detail the mathematical basis of the method, including all necessary computational operations, which enables its application in various decision-making contexts. Through three different scenarios – when all criteria are of the Benefit type, all criteria are of the Cost type, as well as when the criteria are of the mixed type – the flexibility and applicability of the method is demonstrated.

Numerical examples clearly show how the method works in practice, while the performed sensitivity analysis confirms its stability. Namely, the results of the method remain consistent even with minor changes in the weight coefficients of the criteria, which indicates the robustness of the FF-RAWEC approach. Additionally, a comparative analysis with other methods in different decision-

making problems from the literature shows a high correlation of ranks, which additionally confirms the validity and reliability of the proposed method.

All of the above points to the fact that the FF-RAWEC method not only successfully integrates the advantages of Fermatean fuzzy numbers into the decision-making process, but also provides stable and reliable results under different conditions. This method can be particularly useful in situations where it is necessary to make decisions based on uncertain, imprecise or subjective information, which is often the case in real decision-making problems. Future research can be directed towards further application of the method in specific engineering and social contexts, as well as towards its extension through integration with other theories in a hybrid model.

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Conflicts of Interest
The authors declare no conflicts of interest.

References
[1] Özdağoğlu, A., Keleş, M. K., & Şenefe, M. (2024). Evaluation of banks in terms of customer preferences with fuzzy SWARA and fuzzy MOORA integrated approach. Journal of Decision Analytics and Intelligent Computing, 4(1), 216–232. https://doi.org/10.31181/jdaic10007122024o
[2] Tešić, D., Božanić, D., & Milić, A. (2023). A multi-criteria decision-making model for pontoon bridge selection: An application of the DIBR II-NWBM-FF MAIRCA approach. Journal of Engineering Management and Systems Engineering, 2(4), 212-223. https://doi.org/10.56578/jemse020403
[3] Pamučar, D., Božanić, D., & Đorović, B. (2011). Fuzzy logic in decision making process in the Armed Forces of Serbia. Saarbrücken: LAP Lambert Academic Publishing.
[4] Dağıstanlı, H. A. (2024). An Interval-Valued Intuitionistic Fuzzy VIKOR Approach for R&D Project Selection in Defense Industry Investment Decisions. Journal of Soft Computing and Decision Analytics, 2(1), 1-13. https://doi.org/10.31181/jscda21202428
[5] Afaq, S. A., Dwivedi, S., Faisal, M., Jana, S., Habiba, U., & Siddique, M. (2025). Enhancing Fuzzy Multi Criteria Decision Making Technique in Engineering Design Problem. In Applications of Fuzzy Logic in Decision Making and Management Science (pp. 431-452). Springer, Cham. https://doi.org/10.1007/978-3-031-77719-6_24
[6] Monzeli, A., Daneshian, B., Tohidi, G., Sanei, M., & Razaveian, S. (2025). Improving Hospital Efficiency and Economic Performance: A DEA Approach with Undesirable Factors in Tehran Emergency Wards. International Journal of Economic Sciences, 14(1), 90-107. https://doi.org/10.31181/ijes1412025174
[7] Monzeli, A., Daneshian, B., Tohidi, G., Sanei, M., & Razaveian, S. (2025). Improving Hospital Efficiency and Economic Performance: A DEA Approach with Undesirable Factors in Tehran Emergency Wards. International Journal of Economic Sciences, 14(1), 90-107. https://doi.org/10.31181/ijes1412025174
[8] Komatina, N. (2025). A Novel BWM-RADAR Approach for Multi-Attribute Selection of Equipment in the Automotive Industry. Spectrum of Mechanical Engineering and Operational Research, 2(1), 104-120. https://doi.org/10.31181/smeor21202531
[9] Stević, Ž., Karamaşa, Ç., Demir, E., & Korucuk, S. (2025). Assessing sustainable production under circular economy context using a novel rough-fuzzy MCDM model: A case of the forestry industry in the Eastern Black Sea region. Journal of Enterprise Information Management, 38(1), 261-291. https://doi.org/10.1108/JEIM-10-2020-0419
[10] Tufan, D., & Ulutaş, A. (2025). Supplier Selection in the Food Sector: An Integrated Approach Using LODECI and CORASO Methods. Spectrum of Decision Making and Applications, 3(1), 40-51. https://doi.org/10.31181/sdmap31202631
[11] Triantaphyllou, E., & Triantaphyllou, E. (2000). Multi-criteria decision making methods (pp. 5-21). Springer Us.
[12] Puška, A., Štilić, A., Pamučar, D., Božanić, D., & Nedeljković, M. (2024). Introducing a Novel multi-criteria Ranking of Alternatives with Weights of Criterion (RAWEC) model. MethodsX, 12, 102628. https://doi.org/10.1016/j.mex.2024.102628
[13] Trung, D. D., Truong, N. X., Duc, D. V., & Bao, N. C. (2024). Data normalization in RAWEC method: Limitations and remedies. Yugoslav Journal of Operations Research, (00), 20-20. https://doi.org/10.2298/YJOR240315020T

[14] Dündar, S. (2024). Performance evaluation of IPARD-II rural development programs with integrated DIBR-RAWEC methods. Pamukkale University Journal of Engineering Sciences, 31(3), 0-0. https://doi.org/10.5505/pajes.2024.43996
[15] Nedeljković, M., Puška, A., Pamučar, D., & Marinković, D. (2024). Selection of agricultural product sales channels using fuzzy double MEREC and fuzzy RAWEC Method. Agriculture and Forestry, 70(3), 45-58. https://doi.org/10.17707/AgricultForest.70.3.03
[16] Demir, G., & Ulusoy, E. I. (2024). Wind power plant location selection with fuzzy logic and multi-criteria decision-making methods. Computer and Decision Making: An International Journal, 1, 211-234. https://doi.org/10.59543/comdem.v1i.10713
[17] Puška, A. , Božanić, D. , Štilić, A. , Nedeljković, M. and Khalilzadeh, M. (2025). Application of Fuzzy-Rough Methodology to the Selection of Electric Tractors for Small Farms in Semberija. Journal of Fuzzy Extension and Applications, 6(4), 651-668. https://doi.org/10.22105/jfea.2025.482890.1663.
[18] Mohamed, M., Salam, A., & Ye, J. (2024). Selection of sustainable material for the construction of drone aerodynamic wing using Neutrosophic RAWEC. Systems assessment and engineering management, 1, 54-72. https://doi.org/10.61356/j.saem.2024.1295
[19] Senapati, T., & Yager, R. R. (2019). Fermatean fuzzy weighted averaging/geometric operators and its application in multi-criteria decision-making methods. Engineering Applications of Artificial Intelligence, 85, 112-121. https://doi.org/10.1016/j.engappai.2019.05.012
[20] Senapati, T., & Yager, R. R. (2019). Some new operations over Fermatean fuzzy numbers and application of Fermatean fuzzy WPM in multiple criteria decision making. Informatica, 30(2), 391-412. https://doi.org/10.3233/INF-2019-1216
[21] Mishra, A. R., & Rani, P. (2025). Evaluating and Prioritizing Blockchain Networks using Intuitionistic Fuzzy Multi-Criteria Decision-Making Method. Spectrum of Mechanical Engineering and Operational Research, 2(1), 78-92. https://doi.org/10.31181/smeor21202527
[22] Biswas, S., Pamucar, D., Kar, S., & Sana, S. S. (2021). A new integrated FUCOM–CODAS framework with fermatean fuzzy information for multi-criteria group decision-making. Symmetry, 13(12), 2430. https://doi.org/10.3390/sym13122430
[23] Rodgers, J. L., & Nicewander, W. A. (1988). Thirteen Ways to Look at the Correlation Coefficient. The American Statistician, 42(1), 59. https://doi.org/10.2307/2685263
[24] Schober, P., Boer, C., & Schwarte, L. A. (2018). Correlation Coefficients: Appropriate Use and Interpretation. Anesthesia & Analgesia, 126(5), 1763–1768. https://doi.org/10.1213/ANE.0000000000002864
[25] Radovanović, M., Petrovski, A., Cirkin, E., Behlić, A., Jokić, Željko, Chemezov, D., Hashimov, E. G., Bouraima, M. B., & Jana, C. (2024). Application of the new hybrid model LMAW-G-EDAS multi-criteria decision-making when choosing an assault rifle for the needs of the army. Journal of Decision Analytics and Intelligent Computing, 4(1), 16–31. https://doi.org/10.31181/jdaic10021012024r
[26] Biswas, A., Gazi, K. H., Bhaduri, P., & Mondal, S. P. (2025). Site Selection for Girls Hostel in a University Campus by MCDM based Strategy. Spectrum of Decision Making and Applications, 2(1), 68-93. https://doi.org/10.31181/sdmap21202511
[27] Tešić, D., & Bozanic, D. (2023). Optimizing military decision-making: Application of the FUCOM–EWAA–COPRAS-G MCDM model. Acadlore Transactions on Applied Mathematics and Statistics, 1(3), 148-160. https://doi.org/10.56578/atams010303